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THE CHARACTER OF THE STRATIFICATION OF THE SEDIMENTS IN THE RECENT DELTA OF FRASER RIVER, BRITISH COLUMBIA, CANADA[1]

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INTRODUCTION

During the course of an investigation, carried on during parts of 1919 and 1920 by the Geological Survey of Canada in co-operation with the Department of Public Works, of the characteristics of Fraser River, British Columbia, an opportunity was afforded of studying the character and mode of origin of the stratification of the sediments forming the Recent delta of the Fraser. Bottom samples were obtained by means of a bottom-sampling machine which furnished core samples (1) from the sea-bottom deposits in the Strait of Georgia, and (2) from the fresh-water deposits in Pitt Lake, a tidal lake tributary to the Fraser. The object of this paper is to describe the character and mode of origin of the stratification of the Recent delta deposits of the Fraser River, and to contrast the character of the stratification of the sediments being formed in fresh water with that of the sediments being formed in salt water.

The writer is indebted to Dr. W. Bell Dawson, superintendent of the Tidal and Current Survey, Department of the Naval Service, Canada, for information regarding the tides and tidal currents in Fraser River and in Pitt Lake, and to Mr. C. C. Worsfold, district engineer, Department of Public Works, Canada, for information regarding the tides and freshets in Fraser River.

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FRASER RIVER AND ITS RECENT DELTA

The Fraser River is the largest river in British Columbia whose basin lies entirely within the province. It has a length of 790 miles and drains an area of 91,700 square miles. The maximum discharge of the river at Hope (100 miles above its mouth) for the past nine years, as determined by the Dominion Water Power Branch of the Department of the Interior, was in July, 1920, when it amounted to 380,000 c.f.s. During the great flood of 1894, however, the discharge as estimated by officials of the Department of Public Works was nearly 500,000 c.f.s. The average minimum discharge of the river at Hope for the past nine years was 17,000 c.f.s., the lowest being 12,000 c.f.s. There is thus considerable variation from high to low water in each year. The water usually begins to rise in May and reaches its greatest height in June or July. Extreme low water may occur in any month from November to March. During the low-water period the river is affected by ocean tides for a distance of 60 miles above its mouth. The current is reversed in the river by the flood tide, however, only for 30 miles above the mouth. The tides in the Strait of Georgia are declinational in character and are characterized by marked diurnal inequality of the semidaily tides. The mean range at the mouth of the Fraser River is 6.4 feet. The maximum range of the great flood tides is 15 feet and of the great ebb tides 14 feet. These maximum ranges, however, are rarely reached, the average for the large tides—which occur for a few days twice a month near the time of maximum declination of the moon—being about 12 feet for the ebb tides and 13 feet for the flood tides. During the balance of the month the ranges are less. The fact that the river is tidal for a considerable distance above its mouth renders it navigable; for the lack of river water during the low-water stage of the river is largely compensated by the tidal water. The combined ebb-tidal and river discharge of the river, in the main channel near its mouth, is rarely less than 100,000 c.f.s., even during the extreme low-water stage of the river.

The water of the Fraser River is turbid to some extent throughout the year, and is markedly so during freshets; but the amount of material carried in suspension is comparatively small. The average amount of material carried in suspension, as shown by analysis of composite samples of the river water collected triweekly at New Westminster for the period of one year from June 5, 1919, to June 5, 1920, was 62 parts per 1,000,000, and the maximum 230 parts per 1,000,000. The high turbidity of the water is due to comparatively large amounts of very fine material carried in suspension. About half the material carried in suspension during the freshet is composed of silt and clay, a part of which is so fine that it can with difficulty be removed by filtering. The river in its seaward part carries in suspension little material coarser than very fine sand (0.1 to 0.05 mm.), but considerable quantities of medium and coarse sand are moved along the bottom. During the freshet the turbid river water flows out over the sea water in the Strait of Georgia and extends for distances of 10 to 15 miles from the mouth of the river. The color line marking the contact of the river water and the sea water is a striking feature in the Strait of Georgia, near the mouth of the river, where it oscillates backward and forward according to the varying influences of the river, tidal, and wind-induced currents.

The velocities of the currents in the lower part of the river near its mouth vary greatly with the tides and according to the stage of river water. During the freshet the maximum velocity of the combined river and ebb-tidal currents reaches, but rarely exceeds, 5½ knots per hour. During the low-water stage the maximum velocity is about 3½ knots. The inward-flowing flood-tidal current rarely, even during the lowest stage of river water, equals the outward current, although the rise of tide on the flood is more rapid than the fall on the ebb. The ebb-tidal current is the dominant current because it is reinforced by the river current. The sea water enters the river during the freshet only to a very small extent, and only along the bottom of the main channel. During the low-water stage the sea water at times extends on the flood tide as much as 8 miles up the river. The flood-tidal current in the Strait of Georgia runs north and is the dominant tidal current. It has a maximum velocity of about 2 knots. Slack water is very pronounced in the lower part of Fraser River, because of the lack of a deep channel where it enters the river, which prevents sea water from entering the river in flood tide until the tide has reached a considerable height.

The Recent or modern delta of Fraser River has its head, as defined by the point where the first distributary is given off, at the city of New Westminster. It extends west for 19 miles to the Strait of Georgia and, across its seaward front, is 14 miles wide. The surface of the delta is all below the level of high tide, except in a few places, where the surface of peat bogs is a few feet above the general level and the delta land high enough to be reclaimed; this is diked to exclude the flood-tidal and freshet waters. At New Westminster the river is confined between drift ridges or upland areas, which rise 200 to 300 feet above the river. The upland area south of the river marks the inner edge of the delta and extends from a point on the river 3½ miles below New Westminster nearly straight south to Boundary Bay. The delta is bounded on the north by the highland area extending from New Westminster nearly west to Point Grey. In its seaward part on the south side it is interrupted by the highland area of Point Roberts, an island-like drift hill, which has been joined on to the mainland by the construction of the delta. The North Arm of the Fraser flows along the northern border of the delta, the main Fraser flows through the central part, and in the southern part there are a number of smaller outlet channels.

There can be no doubt that the materials composing the delta have been transported to their present resting-place very largely by the river; for it has been shown that the river transports considerable material during its freshet stage, and there is no other apparent source for such a large amount of material. A small part, however, has been and is being derived from wave erosion of the shores, chiefly of the highland area of Point Roberts. A large part of the material composing the delta is sand and silt derived by stream erosion from the vast accumulations of glacial drift which border the banks of the Fraser and Thompson rivers for long distances above the canyon of the Fraser, in smaller part from erosion of the bedrock (granite) in the canyon of the river, and from erosion of the drift deposits in the upper part of the delta area.

The delta is building out into fairly deep water in the Strait of Georgia in spite of the facts that the river is tidal for a considerable distance above its mouth, with a mean tidal range of 6.4 feet and a maximum range of 15 feet at its mouth, and that the seaward front of the delta is swept by fairly strong tidal currents. The outbuilding occurs because of the dominance of the river currents over the tidal currents. The river currents are strong enough to transport large quantities of coarse and fine material which the tidal currents cannot transport into deep water. The tides and tidal currents have the effect, however, of giving an unusual form to the seaward portion of the delta. In its seaward portion the river flows for several miles through sand banks exposed in large part at low tide, but completely submerged at high tide. These banks extend seaward on an average of 4 to 5 miles from the higher delta land and are for the most part nearly level except where channeled by outlet streams. The flood tides and tidal currents tend to cause a diffusion and diversion of the river currents in this part of the delta and prevent the river from building up its banks. The coarse material in the sand banks is gradually moved seaward by the dominance of the combined ebb-tidal and river currents, which tend to carry it seaward, over the flood-tidal currents moving inward. The fine material is kept in suspension until it is carried seaward by the river currents and settles by gravity and through the influence of sea water in causing it to flocculate, or is carried inshore by the flood-tidal or wind-induced currents and lodges in the grass-covered marshes and slack-water channels, tending to build them up and extend the higher delta land seaward. The flood-tidal currents also have the effect of giving to the greater part of the subaqueous front of the delta a smooth, curved outline lacking the finger-like projections characteristic of many deltas.

In structure, the delta presents the forms characteristic of a high-grade delta built into fairly deep water. The fore-set beds are well developed and extend from the 3-fathom line to about the 30-fathom line and have an average dip of about 10°. The dip, however, is irregular, and in places the subaqueous front of the delta is nearly vertical for heights of 1 to 3 fathoms. Below the

30-fathom line the beds slope more gradually seaward, the 100-fathom line being reached at from 1 to 2 miles from the outer edge of the sand banks. The horizontal bottom-set beds, consisting of very fine material, occupy the bottom over a considerable part of the Strait of Georgia, off the mouth of the river. The strait, which is 10 to 15 miles wide, varies in depth in its central part from 100 fathoms to about 225 fathoms. The top-set beds are thinnest and in most places only a few feet in thickness. In places, however, they may be upward of 100 feet thick, as, for example, where a deep channel of the river has been abandoned and has been gradually filled and built up to high-tide level. The top-set beds are sandy in character in their lower part up to about half-tide level, the upper part being silty in character. The silty, fine-grained beds, formed by deposition from flood waters overflowing the river banks, become thicker, progressively, upstream, owing to the fact that freshet waters do not affect the level of high tide in the lower part of the river as far up as Steveston, 6 miles above the mouth, but appreciably affect the level in the upper part of the river. The shore face of the delta is very weakly developed because wave action has little effect owing to the shallowness of the water over the sand banks.

The river, for a distance of 40 miles above New Westminster, is in places bordered by extensive flats, mostly below high-tide, freshet level, which have been formed by the meandering of the river and its tributaries, and by deposition from flood waters. The flats, for the most part, have been carved out of the raised Pleistocene marine clays and delta deposits and form the alluvial flood plain of the river.

PITT LAKE DELTA

An unusual kind of delta is being formed at the lower or south end of Pitt Lake, which drains south by way of Pitt River into the Fraser above New Westminster. The lake is ½ to 2½ miles wide and 15 miles long, and is tidal. During the freshet stage of the Fraser the surface of the water in Pitt River and Pitt Lake is raised several feet above the normal level and falls only slightly with the tides, so that during this time there is very little current into or out of the lake. During the low-water stage, the tides in the lake have a maximum range of about 3½ feet, and there are strong currents both ways. The delta is being built into the lake at the south end, although the drainage of the lake basin is outward or toward the south. This is the case because the inward, flood-tidal current is stronger than the outward current, because the rise of tide on the flood is more rapid than the fall on the ebb, and the outflow of river water is not great enough to counteract this effect.

The delta is partly submerged and extends about 4 miles into the south end of the lake. The top-set beds are exposed in places at extreme low tide, but are for the most part covered by 3 to 6 feet of water. A single, straight river channel extends through the delta. The delta has advanced along the line of the channel and left unfilled a deep depression on its west side. The fore-set beds are well developed and extend to depths of 20 to 30 fathoms, the slope being in places as much as 30°, but for the most part only about 10°. The lake has a maximum depth near its south end of about 50 fathoms. In the narrow parts near the north end the maximum depth is about 80 fathoms.

CHARACTER OF STRATIFICATION OF THE SEDIMENTS

A number of core samples of bottom deposits in the Strait of Georgia, off the mouth of the Fraser and in Pitt Lake, were obtained by means of a bottom-sampling machine. The machine consisted of a hollow casting, 3 feet long, sharpened at the lower end and fitted at the top with a ball valve which worked automatically. The machine weighed 55 pounds and was operated from a motor boat by means of a sounding machine of the ordinary type. The samples were mounted in plaster of paris and sectioned vertically to show the character of the stratification. A number of the samples are shown in Figures 1 and 2.

The stratification of the top-set beds of the Fraser Delta and alluvial flood-plain deposits differs in different parts of the vertical section. Below the level of mean low tide the top-set beds are composed largely of sand, are for the most part horizontally bedded, but in places are cross-bedded and current-ripple-marked. In places there are thick and thin lenses or beds of silt and clay which

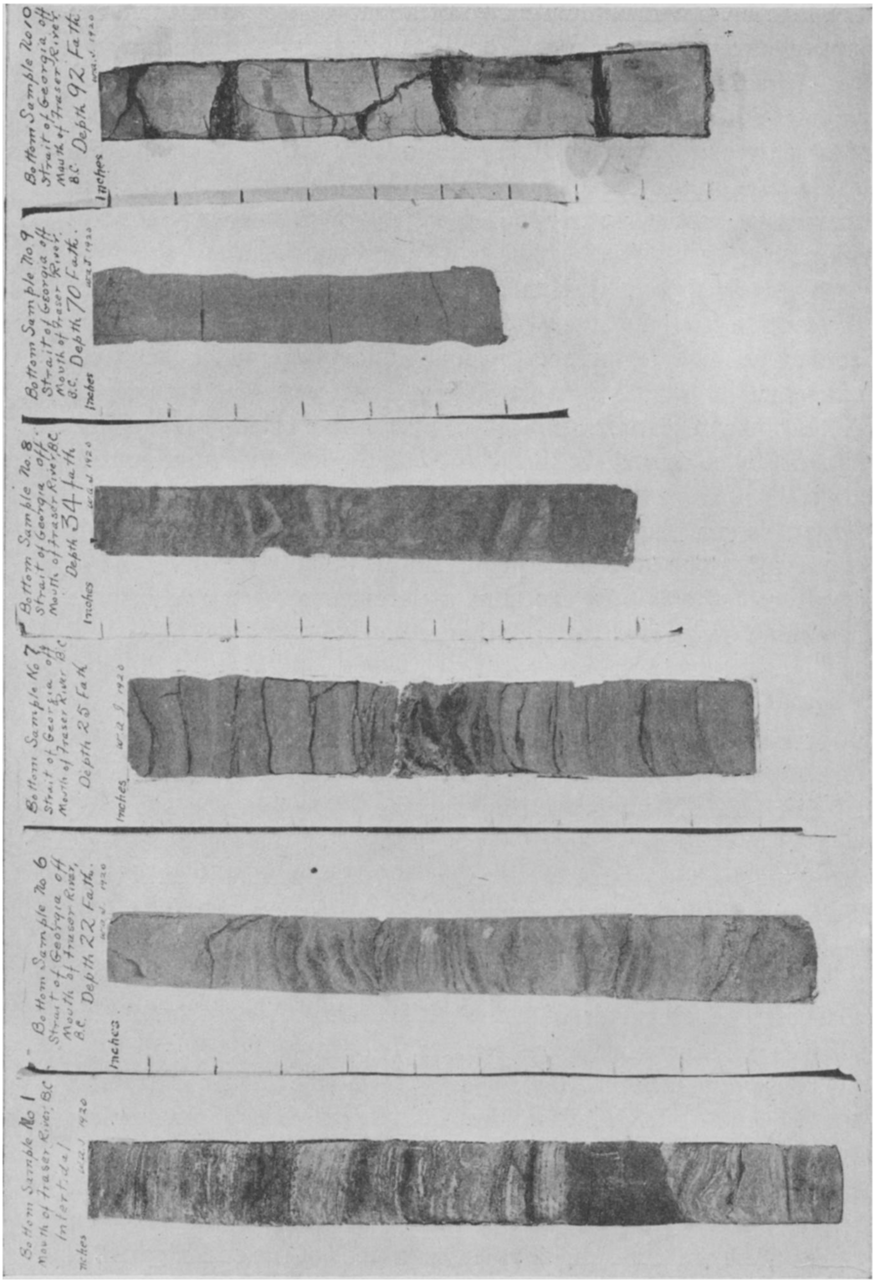
Bottom Sample No 1 Mouth of Fraser River, B.C. Intertidal W.A.J 1920
Inches
Bottom Sample No 6 Strait of Georgia off Mouth of Fraser River, B.C. Depth 22 Fath. W.A.J 1920
Inches
Bottom Sample No 7 Strait of Georgia off Mouth of Fraser River B.C Depth 25 Fath W.A.J 1920
Inches
Bottom Sample No. 8 Strait of Georgia off Mouth of Fraser River, B.C Depth 34 fath W.A.J 1920
Inches
Bottom Sample No 9 Strait of Georgia off Mouth of Fraser River B.C. Depth 70 Fath. W.A.J 1920
Inches
Bottom Sample No 10 Strait of Georgia off Mouth of Fraser River B.C. Depth 92 Fath. W.A.J 1920
Inches

FIG. 1.—Core samples of sediments being formed in the Recent delta of Fraser River, British Columbia, Canada. The samples are mounted in plaster of paris and have been sectioned vertically to show the character of the stratification.

show no definite lamination. The stratification of the sandy beds is in places rendered visible by thin partings of silt and clay. The stratification of the beds in the intertidal zone is very marked, the characteristic feature being a very thin tidal lamination. Bottom sample No. 1, shown in Figure 1, illustrates the character of the stratification of part of the beds in the intertidal zone. The light-colored parts are silty in character and the dark parts are sandy. The seasonal character of these beds is indicated in places by layers of vegetable matter, and in other places by the different character of the laminae formed during the freshet stage of the river, from those formed during the low-water stage. During the freshet the water holds in suspension considerable quantities of silt, and during the low-water stage it is nearly clear. Hence the laminae formed during the freshet are largely silt, and those formed during the low-water stage are largely fine sand. The tidal laminae average possibly 15 to 20 to the inch. The seasonal layers average about 5 or 6 to the foot. But as contemporaneous erosion and deposition are constantly going on, any one section gives a very incomplete record of either the tidal laminae or seasonal layers.

The stratification of the alluvial flood-plain deposits differs from that of the tidal flood-plain deposits because of the fact that during the freshet the surface of the part of the river above New Westminster is raised above the normal level and falls very little with the tides. Hence, during the freshet, a single layer of silt, which may be as much as ½ inch in thickness, is deposited on the alluvial flood plain. Neither the tidal nor the alluvial flood-plain laminae show any marked gradation upward from coarse to fine particles in the individual laminae.

The character of the stratification in the fore-set beds of the Fraser Delta is indicated approximately in samples Nos. 6, 7, and 8 shown in Figure 1. The beds are composed of a mixture of fine sand (0.1 to 0.05 mm.), silt (0.05 to 0.005 mm.), and clay (less than 0.005 mm.). They are, for the most part, thinly laminated, in a somewhat similar manner to the tidal flood-plain deposits. In places the lamination is even, in other places it is markedly irregular, and cross-bedding as well as inclined bedding occurs. The lamination is tidal in character, but is the result of the combined effects of flocculation in sea water, river and tidal currents, and slack water. A leaf bed is shown in sample No. 7 at about mid-length. As it is known from a comparison of soundings made in 1859 and shown on the 1860 chart with those made in 1919 by the Hydrographic Survey of Canada that sedimentation takes place in the fore-set beds, at the points where the samples were taken, at the average rate of about 20 feet per year, it is obvious that the samples would not show evidence of seasonal banding. It is known that coarse material is deposited off the mouth of the river during the freshet, and that this is overlain by finer materials deposited during the low-water stage. Hence the bedding probably has in places a seasonal character, but the annual layers vary in thickness, in different parts of the delta front, from a few inches or even less to as much as 50 feet.

Bottom samples Nos. 9 and 10, shown in Figure 1, are from the fine-grained bottom-set beds of the delta, in the Strait of Georgia. Sample No. 9, from a depth of 70 fathoms, is largely silt, and sample No. 10, from a depth of 92 fathoms, is largely clay, which, because of excessive shrinkage in drying, is badly cracked. The samples as mounted and shown in the figures are smaller in size than in the original state because of compression and shrinkage in drying. Sample No. 10 is most compressed, and, judging by the depth of penetration indicated by the mark left on the outside of the sampling machine, is one-half to two-thirds of its original length. The other samples are more nearly representative of the original thicknesses.

A marked feature of the bottom samples from the fine-grained bottom-set beds is the absence of any trace of lamination either in the beds composed of silt with a mixture of very fine sand, or in the beds composed for the most part of clay. The lack of lamination is due to the well-known effects of flocculation in sea water, which causes the fine silt and clay particles in suspension in the river water to settle to the bottom together when flocculation takes place as the result of the mixing of the two waters. In places also very fine sand settles to the bottom along with the silt and clay. Hence, in the case of the fine-grained materials deposited in sea water, there is a lack of sorting and no definite lamination,

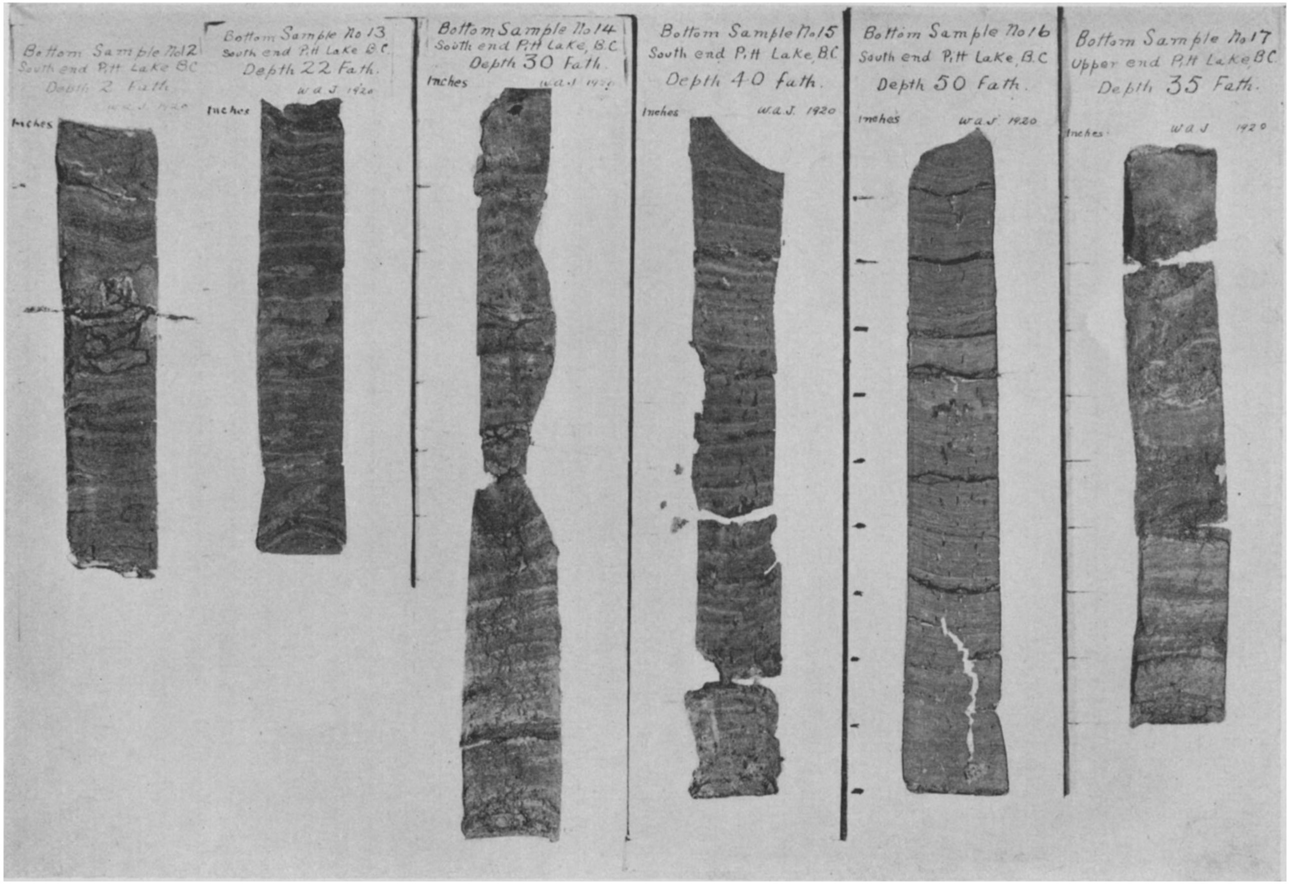

FIG. 2.—Core samples of sediments being formed in Pitt Lake, British Columbia, Canada. The samples are mounted in plaster of paris and have been sectioned vertically to show the character of the stratification.

and the beds are probably thick and massive. As the samples from the bottom-set beds were taken at points where sedimentation is taking place at the rate of at least 1 foot per year, they cannot be taken as criteria of the presence or absence of seasonal banding. It is possible that in places the bedding is seasonal in character, for coarser material is carried out into the strait during the freshet than during the low-water stage of the river.

Samples from the bottom of Pitt Lake are shown in Figure 2. Sample No. 12 is from the submerged top-set beds, samples Nos. 13 and 14 are from the inclined fore-set beds, and samples Nos. 15 and 16 are from the bottom-set beds of the delta at the south end of the lake. Sample No. 17 is from the bottom-set beds of the delta formed by inflowing streams at the north end of the lake.

The character of the stratification of the deposits formed in the tidal fresh-water body differs in several ways from that of the deposits formed in salt water in the Strait of Georgia. Tidal laminae are shown to some extent in all the samples from Pitt Lake. They are exceedingly fine, being in places as many as 100 to the inch. The bedding of the fore-set beds is much more even than that of the fore-set beds of the Fraser Delta, apparently because of the absence of tidal currents along the front of the delta. Samples Nos. 13, 14, and 15 (Fig. 2) were taken at the south end of the lake near the subaqueous front of the delta. They all show a fairly regular recurrence of silty layers (light-colored) separated by sandy layers (dark colored). This banding is probably tidal in character and may be explained as follows. There are two tides daily in Pitt Lake, but one is so small that as a rule the current is not reversed; so that there is nearly always only one period of outflow and one of inflow each day. Large tides occur twice a month near the times of maximum declination of the moon, and small tides occur near the times when the moon is over the equator. The inward current is greater at the period of large tides than at that of small tides. During the times of large tides sand tends to be deposited, and during the times of small tides silt tends to be deposited. The sandy bands separating the silty bands are very thinly laminated and in places contain eight or ten laminae. The silty bands also are in places thinly laminated, but not so definitely as the sandy bands. The rate of deposition in the Pitt Lake Delta is not definitely known, but probably is very small, for a comparison of a number of soundings taken in 1920 with those taken in 1860 shows no great difference. The soundings taken at the point, about 1 mile from the front of the delta, where sample No. 16 was obtained, showed that deposition had taken place to a depth of 5 to 10 feet during the past 60 years, or at the rate of 1 or 2 inches a year. The rate of deposition near the front of the delta is probably much greater. The beds probably show therefore both tidal lamination and tidal banding. They apparently do not show seasonal banding. From the fact that there is very little current in the entrance to Pitt Lake during parts of May, June, and July when the Fraser is in flood, it might be expected that this period would be indicated in the bottom samples by a thick layer of silt. During this period, however, the turbid water of the Fraser does not enter Pitt Lake to any extent and the lake water is nearly clear.

Bottom sample No. 16, taken at a depth of 50 fathoms, is from the bottom-set beds of the delta, in the deepest part of Pitt Lake, near the south end. It is composed of silt and clay and differs markedly in the character of its stratification from the fine-grained samples from the bottom-set beds of the Fraser Delta in the Strait of Georgia in that it is thinly and gradationally laminated. The lamination is probably due to tidal action and to the absence of flocculation of the fine material in suspension in the fresh water, which permits the silt and clay to settle to the bottom at different rates.

Bottom sample No. 17, taken at a depth of 35 fathoms, is from the bottom-set beds or from near the contact of the fore-set bottom-set beds of the delta at the north end of Pitt Lake. It shows in places a tidal lamination and probably also a seasonal banding. There is a fairly regular recurrence of silty layers ½ to 1 inch, separated by sandy layers 1 to 2 inches thick. The silty layers were probably deposited during the freshet when the surface of the lake did not rise or fall appreciably with the tides, and the sandy layers during the periods when the lake was affected by the tides; for at ebb tide the currents in the streams flowing through the delta at the north end of the lake are greatly increased. This appears to be borne out by the fact that in places the sandy layers are thinly laminated.

SUMMARY OF CONCLUSIONS

The tidal flood-plain deposits of the Fraser River are characterized by a very thin lamination which is tidal in origin. The seasonal character of the bedding is shown in places by layers of vegetable material and in other places by alternations of silty layers and sandy layers, both of which show tidal lamination.

The alluvial flood-plain deposits of the Fraser are characterized by seasonal layers of silt and vegetable material.

Neither the tidal nor the alluvial flood-plain deposits show to any marked extent gradational lamination.

The fore-set beds of the Fraser Delta, deposited in sea water, are characterized by a thin lamination which is the result of the combined action of flocculation in sea water, river and tidal currents, and slack water. The beds have in places marked cross-bedding as well as inclined bedding. The fine-grained bottom-set beds are thick and without lamination, because of the effect of flocculation in sea water.

The Pitt Lake Delta deposits formed at the south end of Pitt Lake (a tidal fresh-water lake) are characterized by a very thin lamination and by a banding, both of which are probably tidal in origin. The fine-grained bottom-set beds have a very thin and gradational lamination, which is due to tidal action and to the absence of flocculation in fresh water. They show no definite evidence of seasonal banding. The deposits now forming in the delta at the north end of Pitt Lake have a tidal lamination and probably also a seasonal banding.

A conclusion which may be drawn from the fact that the fine-grained sediments deposited in salt water are not laminated, because of the effects of flocculation, while those formed in fresh water are, is that fine-grained sediments which are evenly and gradationally laminated are fresh-water sediments in origin or, if marine in origin, are glacial; for it is probable that sea water would be sufficiently dilute to prevent flocculation and hence to permit of lamination of the sediments only at times when and in places where large volumes of water from melting ice sheets were being poured into the sea. A possible exception might occur in places where large volumes of river water are being poured into an estuary or into a nearly land-locked part of the sea; but flocculation takes place in the Strait of Georgia in spite of the large volume of fresh water brought down by the Fraser, and where the density of the surface sea water is only 1.010, as compared with the density of normal sea water which at 17.5° C. is 1.027.